A SCHEINER-PRINCIPLE POCKET OPTOMETER FOR SELF-EVALUATION AND BIOFEEDBACK ACCOMMODATION TRAINING

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Most humans tend toward myopia when presented with a visual field without sufficient detail to stimulate focusing mechanisms. This means that a pilot flying in darkness, or in an "empty field" such as empty sky, will be likely to focus nearer the windscreen than at the optical infinity required to focus on visual targets of probable interest. Biofeedback training to counter this problem has been limited in practical application by expensive and cumbersome instrumentation.

A Scheiner-principle optometer has been developed for self-evaluation of accommodative state and biofeedback training. The specific advantages of the new invention over earlier optometers are: (a) simplicity of design; (b) hand held, portable implementation; (c) light weight; (d) small size; (e) low manufacturing cost; (f) the

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19. use of a monochromatic light source to eliminate the effects of chromatic aberrations in the subject's eye; and (g) effectiveness as a training aid.

Four prototypes of the pocket optometer have been built and were used to implement biofeedback training to correct night myopia in 12 Navy aviation candidates. All subjects were emmotropic in full light. Training was limited in duration due to the transient nature of subject availability but was reasonably successful in 10 out of the 12 cases.

SUMMARY PAGE

THE PROBLEM

The need for precise lens accommodation to bring visual targets into sharp focus on the retina is far more urgent at night, when contrast is very low, than in bright daylight. Out-of-focus visual targets have a light distribution that is spread over a larger area on the retina . This greatly increases the probability that the contrast of the target relative to the background will fall below the threshold for detection. Unfortunately, many individuals do become myopic at night, further reducing the quality of an already poor visual image. In many professions, this phenomenon, sometimes called the "dark focus of accommodation," is of little consequence. For pilots flying at night, however, it can mean the difference between life and death.

A reliable screening instrument capable of measuring refractive state in the dark could provide useful preventive information. When this refractive state is also made cognitively available to individuals as they accommodate, a means of implementing a biofeedback training paradigm exists. While biofeedback training to correct night myopia is not new, devices previously used are extremely expensive and require a trained technician to operate.

FINDINGS

1. A Scheiner-principle optometer was developed for the self-evaluation of accommodative state and biofeedback training to remedy undesirable conditions such as dark- or empty-field myopia. The specific advantages of this new invention over earlier optometers are: a) simplicity of design, b) hand held, portable implementation, c) light weight, d) small size, e) low manufacturing cost, f) the use of a monochromatic light source to eliminate the effects of chromatic aberrations in the subject's eye, and g) effectiveness as a training aid.

2. Four prototypes of the pocket optometer described in this report have been built and were used to implement biofeedback training to correct night myopia in 12 Navy aviation candidates. All subjects were emmetropic in full light. Training was limited in duration due to the transient nature of subject availability but was reasonably successful in 10 out of the 12 cases.

RECOMMENDATION

A large body of literature indicates that night myopia is ubiquitous in the population as a whole. We know, on purely optical grounds, that an out-of-focus and poorly illuminated target will not be as readily detected and/or identified as one that is in focus. This is the reason the Navy has been interested in this problem.

The possibility remains that accommodation, being somewhat under volitional control, is directed myopically by the instrument used to measure it. The instrument described in this report is, indeed, usually close to the subject, and the subject knows it. In a darkened experimental situation, subjects could reasonably be expected to adjust their accommodation to the optical distance of the instrument being used. Thus, the measure of "night myopia" may actually be a related phenomenon known as "instrument myopia." Furthermore, if the training paradigm used in this study addresses instrument myopia only and does not transfer directly to night myopia, it is of little practical value. Although remote given the research effort in this field, such a possibility must be discounted experimentally. If this effect can be successfully discounted, then the "pocket optometer" described in this report and suitable instructions for its use should be made available to the fleet as soon as possible, particularly in view of what appears to be a recent Navy emphasis on night operations.

Acknowledgment

I wish to give special thanks to ENS Robert Young, who diligently recruited subjects and collected the data presented here.

INTRODUCTION

The need for precise lens accommodation to bring visual targets into sharp focus on the retina is far more urgent at night, when contrast is very low, than in bright daylight. Out-of-focus visual targets have a light distribution that is spread over a larger area on the retina. This greatly increases the probability that the contrast of the target relative to the background will fall below the threshold for detection. Unfortunately, many individuals do become myopic at night, further reducing the quality of an already poor visual image. In many professions, this phenomenon, sometimes called the "dark focus of accommodation," is of little consequence. For pilots flying at night, however, it can mean the difference between life and death.

A reliable screening instrument capable of measuring the refractive state of individuals in the dark could provide useful preventive information. When this information is cognitively available to subjects as they accommodate, a means of implementing a biofeedback training paradigm exists.

Biofeedback training to correct night myopia is not new. For example, Randle (1) demonstrated successful biofeedback accommodation training using a Stanford Research Institute dual Purkinje image eye-tracker with optometer attachment and auditory feedback. Other devices, such as Trachtman's (2) apparatus for accommodation training, could be used in a similar fashion. Both these devices are extremely expensive and require a trained technician to operate.

In response to the problems outlined above, I developed a Scheiner-principle optometer for self-evaluation of accommodative state and biofeedback training to remedy undesirable conditions such as dark- or empty-field myopia. The purpose of this report is to describe the new optometer and to present limited data obtained with its use in biofeedback training to accommodate at infinity in the dark.

BACKGROUND AND GENERAL DESCRIPTION

The "pocket" optometer described in this report is based on concepts by Scheiner and Young. Scheiner (3) divided an image into a plurality of images with the use of multiple small apertures placed close to the eye. The multiple apertures, usually two, divide the image into a number of images equal to the number of apertures. These images remain essentially in focus due to the long depth of field afforded by small apertures. If, however, the subject's eye is accommodated at a distance that coincides with the distance of the object being viewed, then the images overlap on the retina and only one is discerned.

Young (4) elaborated Scheiner's practice by placing a fine string on a dark bar extending from close to the eye to a distance encompassing the range of accommodation of interest. Two Scheiner-principle apertures cause the image to be brought to coincidence at the point of accommodation but to diverge beyond and before that point. This effect presents an "X" on the retina; the crossing point of the "X" being the image from that point on the string at the exact distance of accommodation. Young's device is elegant in concept but limited in range to the length of dark bar and string used. Accommodative distances beyond infinity are impossible with this device, and accommodative distances approaching infinity are limited by structural constraints.

The limitation in range of accommodation of Young's optometer is overcome in the design reported here by placing a positive lens between the "string" of Young's optometer and the Scheiner-principle apertures. A positive lens so placed has a focal distance physically closer than infinity. This shortens the entire apparatus considerably, and also extends the measurement range of the apparatus to beyond infinity if the focal distance of the lens is less than the physical length of the apparatus.

The prototype optometers used in the study reported below contain a 20-diopter (D) lens, giving a focal distance of 5 cm and an effective dioptric divergence (from the perspective of the subject) of 4 D/cm away from the focal distance of the lens. A scale slightly longer than 5 cm (corrected for angle of incline relative to the axis of the lens) was used, with the center of the scale at one focal distance from the lens. This scale was marked every quarter and eighth centimeter as diopter and half diopter marks respectively. These devices have a range of plus or minus 10 D.

Subjects using this "pocket" optometer see an "X" image with each "leg" of the X being a scale. The state of accommodation is indicated by the placement of the intersection of the two scales. Subjects may directly read the scales and either note or report this information as required, or they may attempt to manipulate their accommodation to achieve some desired end. The fundamental necessary condition of any biofeedback training paradigm is to bring the physiological phenomenon of interest directly and concurrently into consciousness. The optometer disclosed herein does exactly that.

MATERIALS AND METHODS

THE POCKET OPTOMETER

Figure 1 shows the subject's eye [1] looking into a pinhole aperture stop plate [2] with two pinhole aperture stops [3 and 4] located horizontally equidistant from the center of the pinhole aperture stop plate with a distance between centers of approximately 3 mm. A positive Badal lens [5] is placed proximal to the pinhole aperture stop plate with the optical axis of the lens coincident with the center of the pinhole aperture plate. A scale [6] is placed adjacent to the lower edge of the Badal lens at the scale's lower end and inclined away from the lens such that the center of the scale is located on the optical axis of the lens at a distance of one focal length of the lens. The upper end of the scale is at a height above the optical axis of the Badal lens equal to the distance below the optical axis of the Badal lens of the lower end of the scale.

The scale is comprised of a photographic negative with scale markings transparent to facilitate back lighting. The center of the scale, at one focal length of the Badal lens, is distinctively marked with a long horizontal line. Major scale markings represent a subject's dioptric deviation

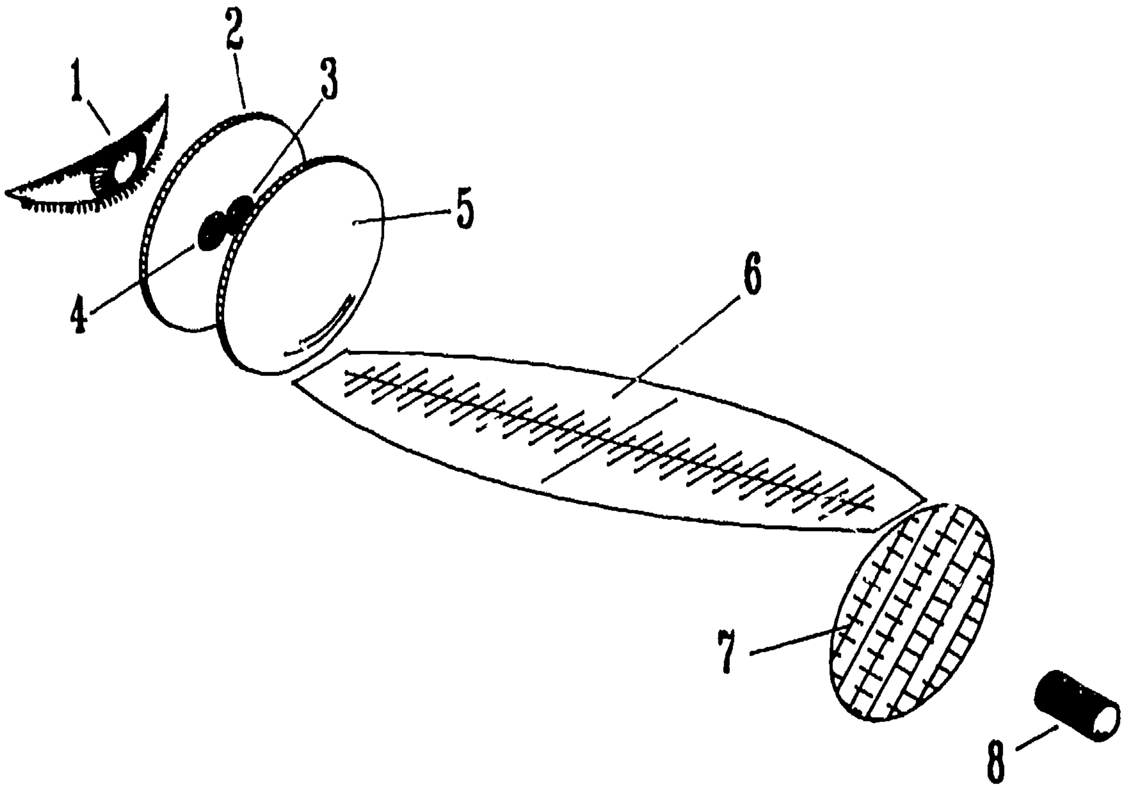

Figure 1. Schematic of the pocket optometer. [1], subject's eye; [2], pinhole aperture stop plate; [3] and [4], pinhole apertures; [5] Badal lens; [6] scale; [7], diffuser; [8], light emitting diode.

from infinity, or the long horizontal line, if the subject should perceive the intersection of the two visible scales at that particular scale marking.

Scale marking distances may be calculated using the following relationship:

$$S_d = B^2M-B$$

where S_d is the subject's dioptric deviation in diopters, B is the power of the Badal lens in diopters, and M is the distance between the Badal lens and scale-marking in meters. The distances so derived are for the optical axis of the Badal lens and must be trigonometrically expanded to account for the incline of the scale relative to the optical axis. Solving the equation gives the lens power required to correct a subject's eye to infinity. That is, negative numbers indicate myopia, and positive numbers indicate hyperopia.

The pocket optometer also allows for back-illumination of the scale using a diffusing screen [7] and a light emitting diode [8]. The light-emitting diode should be of a narrow-bandwidth type to minimize chromatic aberrations within the eye. If it emits principally at about 585 nm (yellow light), the resultant measurements will be roughly equivalent to measurements made with white light. A commercially available example of an appropriate light-emitting diode is the HLMP 3850. The apparatus shown in Fig. 1 may be contained within a tube or other structure and provided with power supply, such as a battery, by means apparent to those of ordinary skill.

Figure 2 depicts images as may be seen by emmetropic, myopic, and hyperopic individuals. In the emmetropic condition [9], the two visible scales intersect the major horizontal line, indicating one focal length of the Badal lens. A myopic subject [10] sees the two visible scales intersect the fifth major scale-marking below the major horizontal line of the scale, indicating 5 D of myopia. To the hyperopic individual [11], the intersection of the two visible scales is coincident with three and a half major scale-markings above the major horizontal line of the scale, indicating 3 1/2 D of hyperopia. These images assume an orientation of the optometer as depicted in Fig. 1; that is, with the end of the scale closest the subject at the bottom of the instrument as it is held.

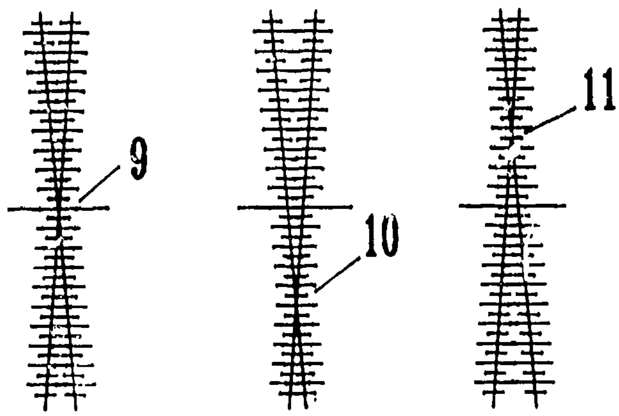

Figure 2. Three views into the pocket optometer. [9], emmetropia; [10], myopia; and [11] hyperopia.

BIOFEEDBACK TRAINING

Twelve Navy aviation candidates participated as volunteer subjects to attempt biofeedback training to correct night myopia using the pocket optometer described in this report. All subjects were emmetropic in full light and possessed the excellent vision required of personnel aspiring to become Navy pilots. All subjects were screened for night myopia in the dark, using a vernier optometer described previously (5).

Any subject exhibiting night myopia was briefed about the purpose of the study and allowed to practice with the pocket optometer. Practice sessions were limited to no more than 1 h with no more than two sessions per day. Most subjects elected to practice once per day for about 40 min. No specific instructions about how to actually change accommodative state were given, as they are not known.

RESULTS

Da[illegible]rom 12 subjects attempting to correct a condition of night myopia [illegible]ng the pocket optometer are plotted in Fig. 3. All data points are mea[illegible]nd standard deviations of 20 readings from a vernier optometer described previously (5). The first data point on the left was a pre-screen condition. Subsequent data points were taken following approximately 40-min training sessions with prototypes of the pocket optometer. Most subjects made good progress with their night myopia after relatively few training sessions.

DISCUSSION

A pilot's vision is a primary asset. Out-of-focus vision is never as good as it can be and could affect target detection. A simple experiment illustrates this point. First, observe some stars on a clear night with normal, corrected vision. Then de-focus with a lens in the line of sight. A surprising number of the lesser stars will disappear. The brighter stars will remain visible even though they are out of focus.

A pilot viewing distant objects at night will probably not be myopic (assuming normal emmetropic vision). The distant objects will direct the pilot's accommodation to infinity, thus facilitating target detection. Without distant objects (e.g., as happens when flying under clouds at night), the situation changes. The only objects available to direct accommodation are close at hand, like instruments or small reflections from the inside surface of the canopy. Under these conditions, a pilot may become a victim of night myopia and not even realize it. As soon as something in the distant visual field becomes bright enough to become detectable, it may also become bright enough to stimulate the accommodation mechanism and be brought quickly into focus. Thus, without an out-of-focus experience, pilots have no difficulty with their vision and remain unaware of any problem, but they also do not detect the distant target until it becomes bright enough to <u>overcome</u> an out-of-focus condition. Becoming "brighter" generally correlates with becoming closer. In many hostile situations, distance is a pilot's best friend.

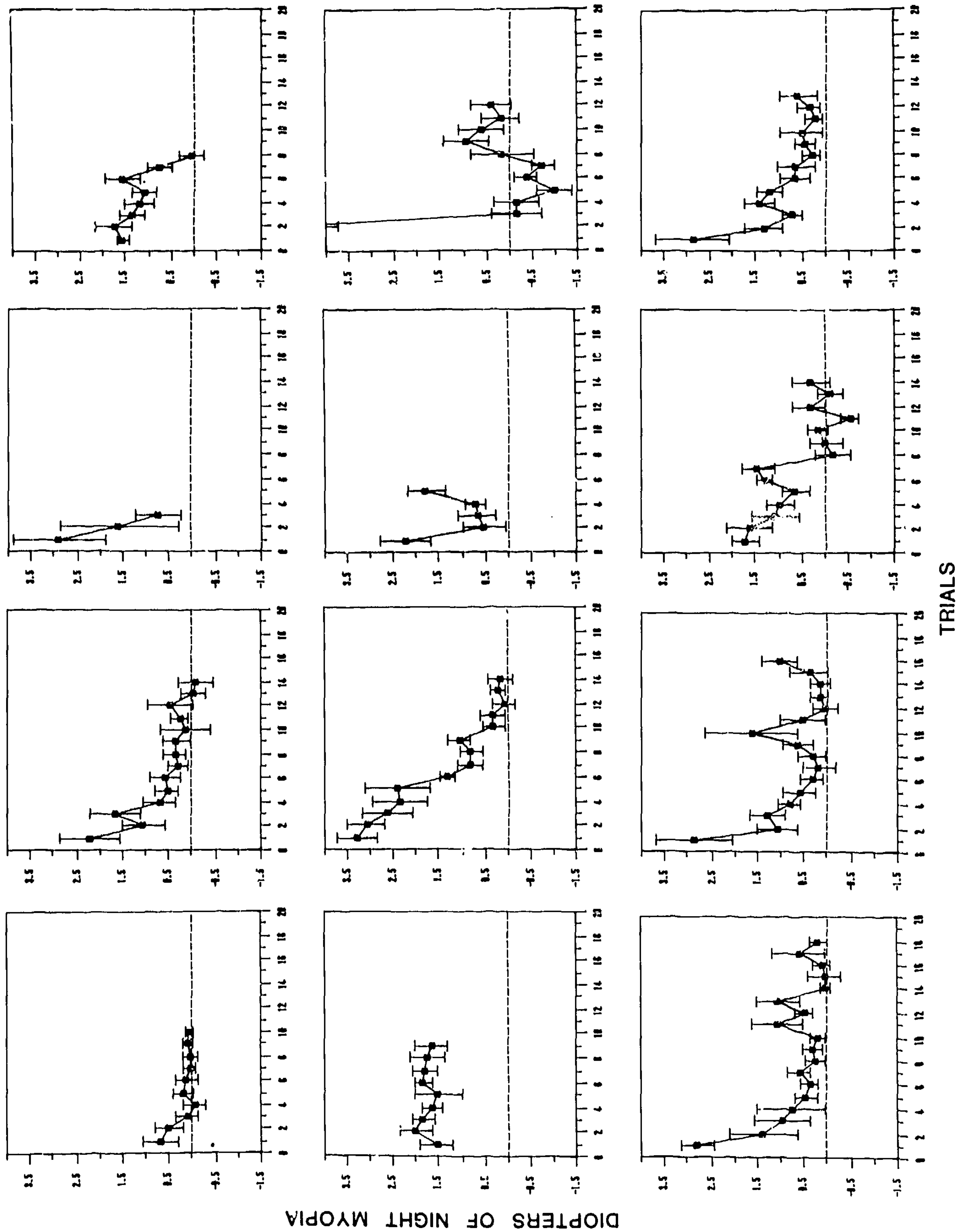

Figure 3. Data from 12 subjects. The first trial is a pre-screen condition. Subsequent trials are taken after training with the pocket optometer. All data points are means and standard deviations of 20 readings taken with a vernier optometer (5).

Pilots are notoriously protective of their right to stay in the air. Rather than report any difficulties they may be having with their vision they may prefer to hide them (assuming that they notice any). The data presented above strongly indicate a positive effect due to practice with the pocket optometer. This optometer could be manufactured at low cost and disseminated to the fleet. There, pilots could evaluate themselves and correct any deficiencies found without further delay.

One important caveat must be mentioned. Most of the literature concurs that the phenomenon of night myopia exists and is ubiquitous in the population as a whole. Related "anomalous myopias" such as "empty field myopia" and "instrument myopia" are also prevalent. Still, the conjunction of two facts remains troubling: 1) a capacity for volitional control of accommodation exists (it was manipulated in the study reported here), and 2) the instruments used to measure night myopia are almost always close to the subject. The possibility arises that the experimental results reported here result from instrument myopia only and no transfer takes place to night myopia. Perhaps, the simple proximity of the measuring instrument may be sufficient to drive accommodation to myopic states. This issue is, in principle, relatively simple to resolve but requires a great deal of experimental work. Potential subjects must be screened and trained as above in conjunction with an operationally realistic "spot detection" task at actual optical infinity. In this way, we will know if training positively affects an operationally significant skill. We are pursuing this goal at present.

RECOMMENDATION

Further research must be undertaken to determine if, in fact, training with the pocket optometer is of actual operational benefit to a pilot. The results of this study appear promising. If further study with operationally significant parameters demonstrates actual visual improvement at night, we recommend that the pocket optometer be manufactured and disseminated to the fleet along with appropriate instructions.

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